On the Rigidity Modulus and Its Temperature Coefficient of the Alloys of Cobalt, Iron and Chromium

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On the Rigidity Modulus and Its Temperature Coefficient of the Alloys of Cobalt, Iron and Chromium.*

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Synopsis

The mean temperature coefficient of rigidity modulus in a temperature range of 20° to 50° of the alloys of cobalt, iron and chromium containing 50 to 90 percent of cobalt and less than 20 percent of chromium has been measured by a torsion pendulum method. The temperature coefficients of most alloys are negative, while as the concentration approaches the composition of stainless invar (Co=54%, Fe=36.5%, Cr=9.5%), the coefficient diminishes, first gradually and then rapidly, becomes zero at a certain composition and afterwards changes its sign. Then the coefficient reaches a conspicuous positive maximum ($+35.9\times10^{-5}$) at the concentration of stainless invar. Thus, there are many alloys having zero coefficient in this ternary system. These alloys were called Co-elinvar. The foregoing results are similar to those obtained previously by the present investigators for the temperature coefficient of Young's modulus, except that in the case of rigidity modulus, the range showing positive coefficient and the position of the positive maximum are situated at the concentrations of higher cobalt and lower chromium than in the case of Young's modulus.

Further, the rigidity modulus at 20° of the alloys has also been determined, with the result that the modulus shows a maximum value (9.34×10^5 kg/cm^2) in the alloy containing 50 percent of cobalt and 5 percent of chromium and a minimum (5.92×10^5 kg/cm^2) in the one containing 65 percent of cobalt and 8 percent of chromium.

I. Introduction

According to the rule(1) on the cause of a small coefficient of the thermal expansion of invar (Fe=64%, Ni=36%) which was proposed previously by one of the present investigators, they measured later the temperature coefficient of Young's modulus of the alloys of cobalt, iron and chromium(2) and found that there are two groups of alloys, one of which has a positive coefficient and the other a negative; thus, there are many alloys having zero coefficient which have been named "Co-elinvar" by the present investigators (Fig. 1).

Lately, it is required to be known the temperature coefficient of the rigidity modulus in order to use co-elinvar as the material for the spring of a seismograph, a spring balance and other measuring equipments. Hence, the present investigators have measured the rigidity modulus and its temperature coefficient of the alloys of

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* The 673rd report of the Research Institute for Iron, Steel and Other Metals. Read at the autumn meeting of the Japan Institute of Metals, Nov. 3, 1949 and published in Nippon Kinzoku Gakkai-si (J. Japan Inst. Metals), **16** (1952), 125.

(1) H. Masumoto, Sci. Rep. Tohoku Imp. Univ., **20** (1931), 101; Kinzoku-no-Kenkyu, **8** (1931), 237.

(2) H. Masumoto and H. Saitô, Nippon-Kinzoku-Gakkai-Si; **6** (1942), 122; **8** (1944), 513; Sci. Rep. RITU., **A 1** (1949), 17.

cobalt, iron and chromium with specimens in a form of thin wire. In the following lines, the result of the present investigation will be described.

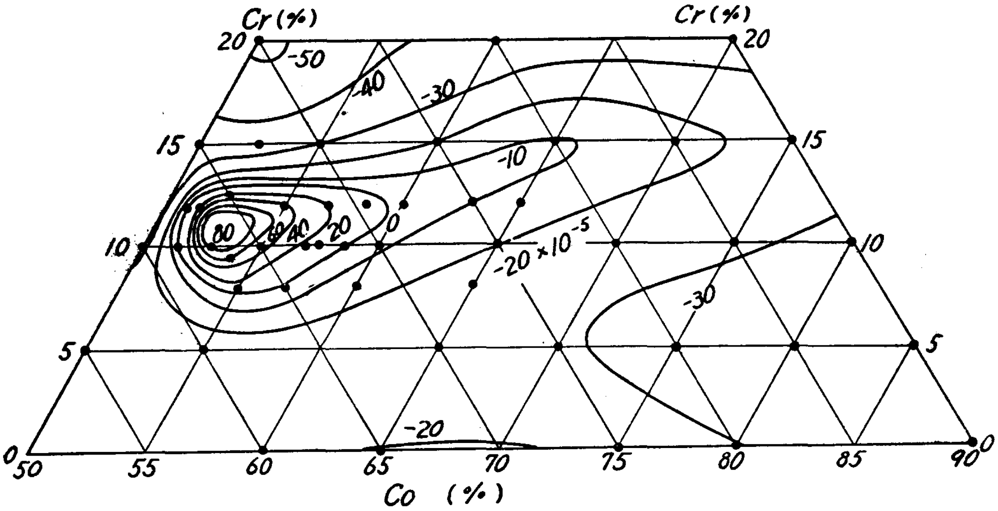


Fig. 1. Projection Diagram of the Curves of the Isotemperature-coefficient of Young's Modulus of Co–Fe–Cr Alloys.(2)

II. Specimens and method of measurement

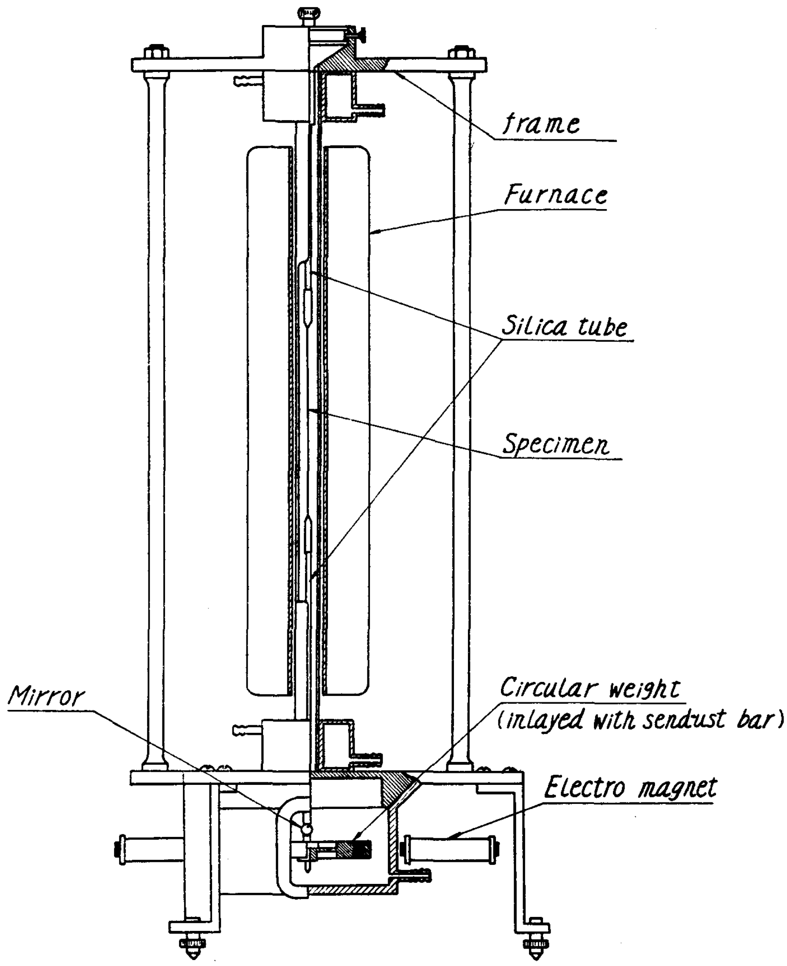


Fig. 2. Measuring Apparatus.

For the present investigation, the forged alloys used in preparing the specimens for the measurement of Young's modulus and its temperature coefficient(2) were used again. The composition of the alloys used is shown in Table 1. They were drawn into a wire, about 0.5 mm thick, and a proper length of it was cut off for the specimen.

All the specimens were annealed at 1,000° for 1 hour in a vacuum furnace and then cooled down to room temperature within it.

The measurement of the rigidity modulus and its temperature coefficient was made by the usual tortion pendulum method(3). An

(3) P. Chevenard, Trav. et Mém. du Bur. Int. des Poids et Mesures, **17** (1927), 44.

outline of the apparatus used is shown in Fig. 2. The upper end of the specimen of an effective length of about 15 cm was fixed to the rigid frame through a thin silica tube, and at its lower end a circular weight made of pure copper was suspended through the other thin silica tube. The total weight of the pendulum was 688.4 grams and its moment of inertia 10,370 g/cm^3. Two small sendust rods were inlayed symmetrically on a diameter of the circular weight. Thus the tortional motion of the pendulum can be excited by two electromagnets set at the outside of the apparatus.

Table 1. Composition of Alloys and Results of Measurement.

Composition (%)			G (kg/cm^2)	α (20°～60°)	g (20°～50°)
Co	Fe	Cr			
60	40	0	7.00×10^{-5}	9.6×10^{-5}	-18.9×10^{-5}
65	35	0	7.66	9.6	−23.0
75	25	0	7.19	10.5	−34.3
80	20	0	6.71	11.7	−37.0
90	10	0	6.52	11.7	−22.2
50	45	5	9.34	9.3	−22.1
55	40	5	9.09	9.5	−25.7
65	30	5	7.01	9.6	−29.8
70	25	5	6.48	9.7	−33.7
75	20	5	6.67	10.7	−33.4
80	15	5	6.77	10.5	−39.3
85	10	5	7.58	11.4	−39.2
55	37	8	7.28	6.0	+23.4
57	35	8	7.20	3.1	+17.9
60	32	8	6.55	6.6	− 2.5
65	27	8	5.92	8.0	−17.5
54	36.5	9.5	7.35	0.1	+35.9
50	40	10	7.03	12.0	−44.8
51.5	38.5	10	7.70	8.7	−31.5
53	37	10	7.66	0.2	+11.4
55	35	10	7.24	1.4	+28.9
57	33	10	6.98	3.8	+17.6
57.5	32.5	10	6.94	3.5	+10.1
58.5	31.5	10	7.11	5.4	+ 5.1
60	30	10	7.04	5.1	− 0.2
65	25	10	6.97	7.5	−17.2
70	20	10	7.14	8.8	−26.1
75	15	10	7.34	9.5	−28.9
80	10	10	7.53	13.5	−31.9
51	37	12	8.41	13.1	−42.9
55	33	12	8.30	12.0	−23.0
57	31	12	8.09	6.0	+ 6.5
58.5	29.5	12	7.74	6.0	+ 1.0
60	28	12	7.44	7.6	− 4.3
63	25	12	7.39	7.8	−12.3
65	23	12	7.78	8.0	−16.0
50	35	15	8.57	16.0	−49.8
52.5	32.5	15	8.31	15.6	−42.7
55	30	15	8.42	15.4	−34.8
60	25	15	8.16	14.0	− 0.9
65	20	15	8.09	9.5	−30.1
70	15	15	8.21	10.2	−37.0
50	30	20	9.12	16.3	−45.4
60	20	20	8.75	14.8	−44.7

The specimen was covered with a silica tube and a non-inductive furnace was set outside the tube. The temperature difference over the full length of the specimen was kept smaller than 1°. The temperature of the specimen was measured with an alumel-chromel thermocouple.

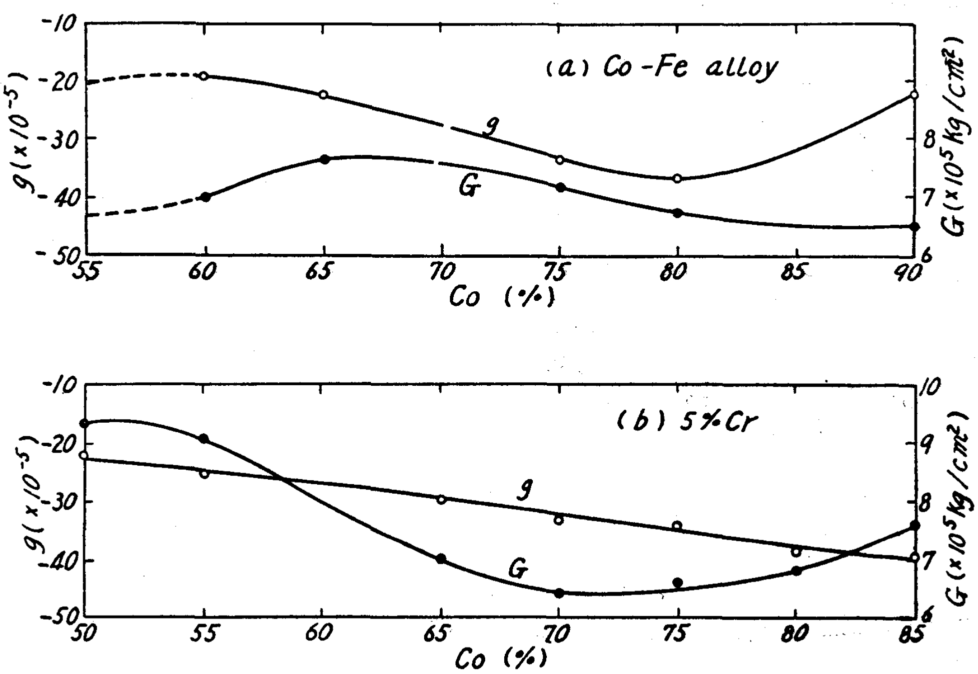
For the measurement, the maximum torsional angle of the pendulum was always taken under 1°. And the time of 1000 rotating oscillations was measured at each temperature with a stopwatch put in a thermostat.

Thus, the rigidity modulus at 20° and its temperature coefficient in the range of 20° to 50° of the ternary alloys were determined. To calculate the temperature coefficient, the coefficient of thermal expansion must be given. So, the present investigators used the ones obtained previously by one of them(4).

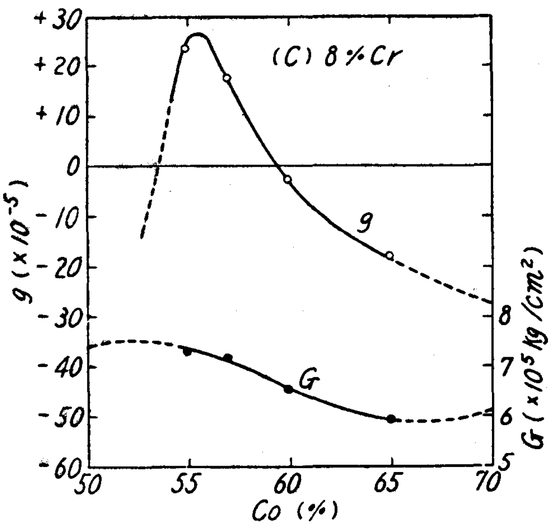
III. Results of measurement

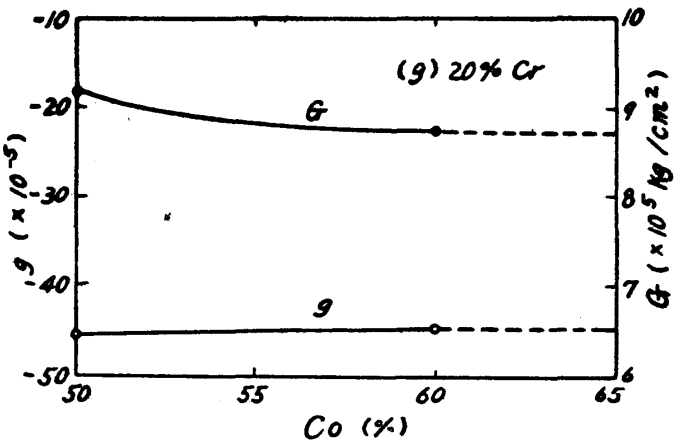
The results of measurement are given in Table 1. In the table, G shows the value of rigidity modulus, α the coefficient of thermal expansion measured previously by one of the present investigators(4) and g the temperature coefficient of rigidity modulus. These results are graphically shown in Figs. 3(a)~(g), in which the abscissa represents the alloying concentration and the ordinate the measured values. Fig. 4(a) is a space diagram which shows the relation between the rigidity modulus and the concentration of the alloys of cobalt, iron and chromium, and Fig. 4(b) a projection diagram of the iso-modulus curves on the basal plane of concentration. Figs. 6(a) and (b) represent respectively a space diagram and a projection diagram

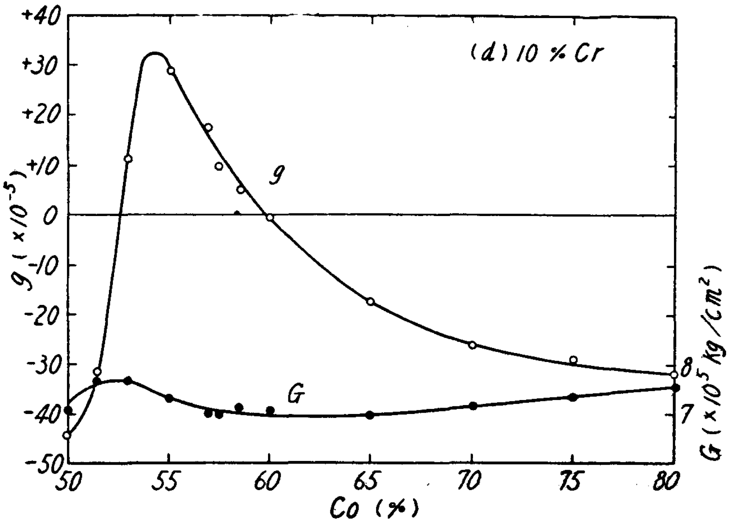
Fig. 3. Relations between the Rigidity Modulus G or Its Temperature Coefficient g and the Concentration of Co–Fe–Cr Alloys.

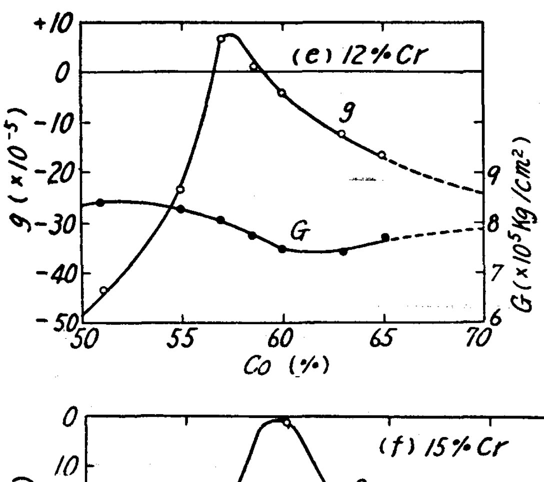


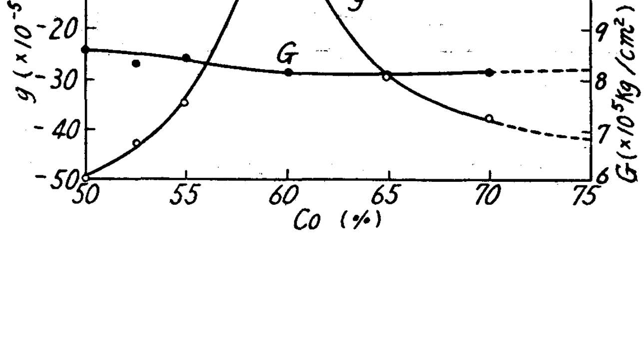
(4) H. Masumoto, Sci. Rep., Tohoku Imp. Univ., **23** (1934), 265; Nippon-Kinzoku Gakkai-Si, **4** (1938), 141.











of the temperature coefficient of rigidity modulus.

(1) Rigidity modulus

As seen in Fig. 3, the rigidity modulus-concentration curve of cobalt-iron alloys has a maximum at the concentration of about 67 percent of cobalt and a minimum at about 87 percent of cobalt. The positions of the maximum and the minimum move towards the lower concentration of cobalt as chromium is added to the alloys. And from Fig. 4, we see that in either side of the valley of rigidity modulus, one maximum appears. The least value of the modulus is 5.92 $\times 10^5$ kg/cm^2 obtained in the alloy containing 65 percent of cobalt, 27 percent of iron and 8 percent of chromium and the greatest, 9.34×10^5 kg/cm^2 in the alloy of 50 percent of cobalt, 45 percent of iron and 5 percent of chromium.

The foregoing results are qualitatively similar to those for Young's modulus obtained previously by the present investigators (Fig. 5)[2], except that the position of the least value of rigidity modulus shifts towards the concentration of higher cobalt than in the case of Young's modulus.

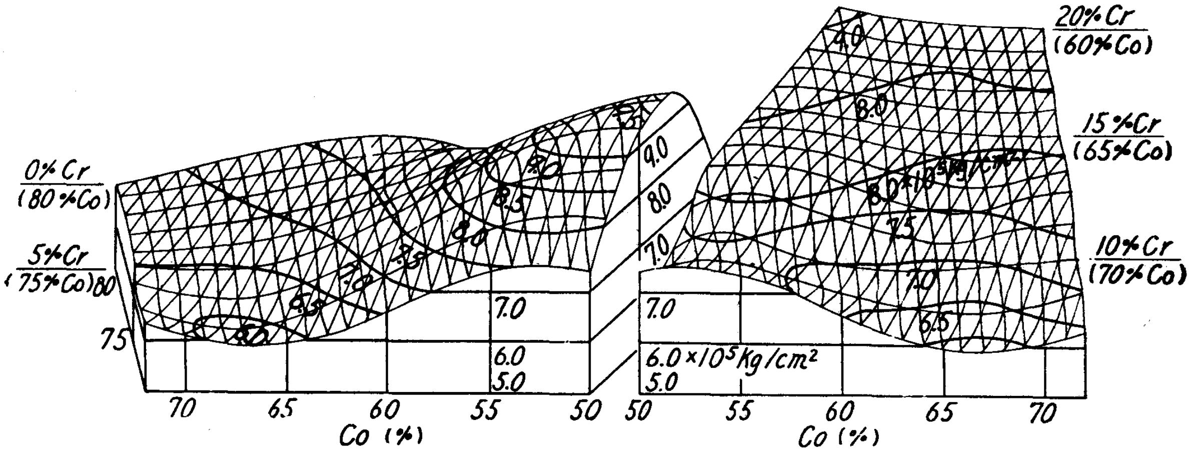


Fig. 4(a). Space-diagram Showing the Relation between the Rigidity Modulus and the Concentration of Co–Fe–Cr Alloys.

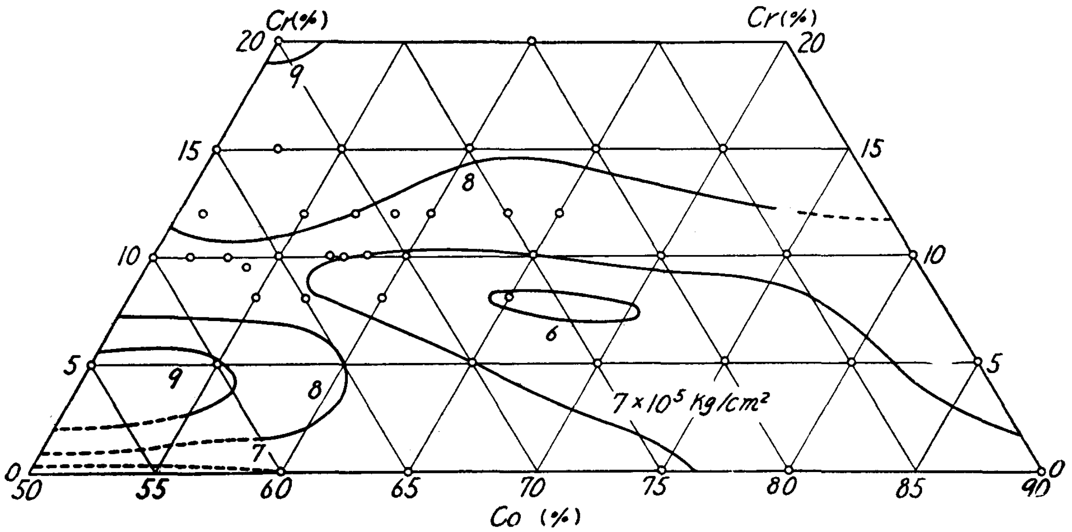


Fig. 4(b). Projection-Diagram of the Isorigidity-Modulus of Co–Fe–Cr Alloys.

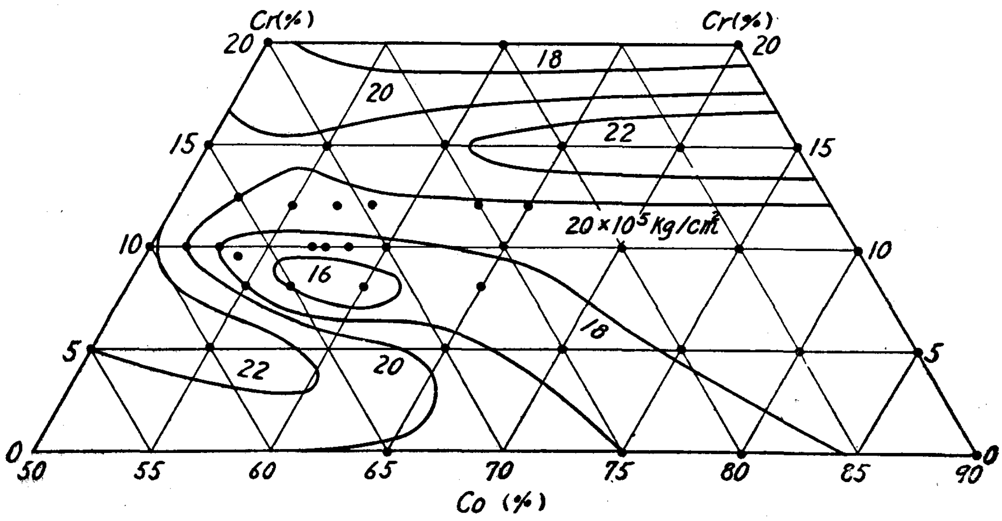


Fig. 5. Projection-Diagram of the Isoelasticity Curves of Co–Fe–Cr Alloys.

(2) Temperature coefficient of rigidity modulus

As seen in Figs. 3 and 6, the temperature coefficient of the rigidity modulus of most alloys in the measured concentration range is negative and of common order, while as the concentration approaches the composition of stainless invar, the coefficient diminishes first gradually and then rapidly, becomes zero at a certain concentration and afterwards changes its sign. Then the coefficient reaches a conspicuous maximum value of $+35.9\times10^{-5}$ at the concentration of 54 percent of cobalt, 36.5 percent of iron and 9.5 percent of chromium; that is, at the composition of stainless invar, the temperature coefficient of rigidity modulus shows a positive maximum as expected.

These results are almost similar to those for the temperature coefficient of Young's modulus(2) obtained by the present investigators (Fig. 1), but in the case of the rigidity modulus the range of the positive coefficients and the positive maximum are situated at the concentrations of higher cobalt and lower chromium than in the case of Young's modulus. This discrepancy may probably be caused by the difference of the texture due to the degree of cold-drawing of the specimen.

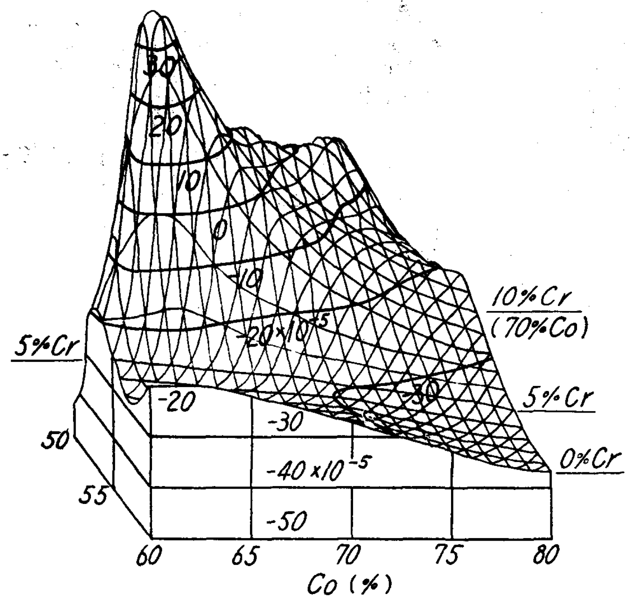


Fig. 6(a). Space-Diagram showing the Relation between the Temperature Coefficient of the Rigidity Modulus and the Concentration of Co-Fe-Cr Alloys.

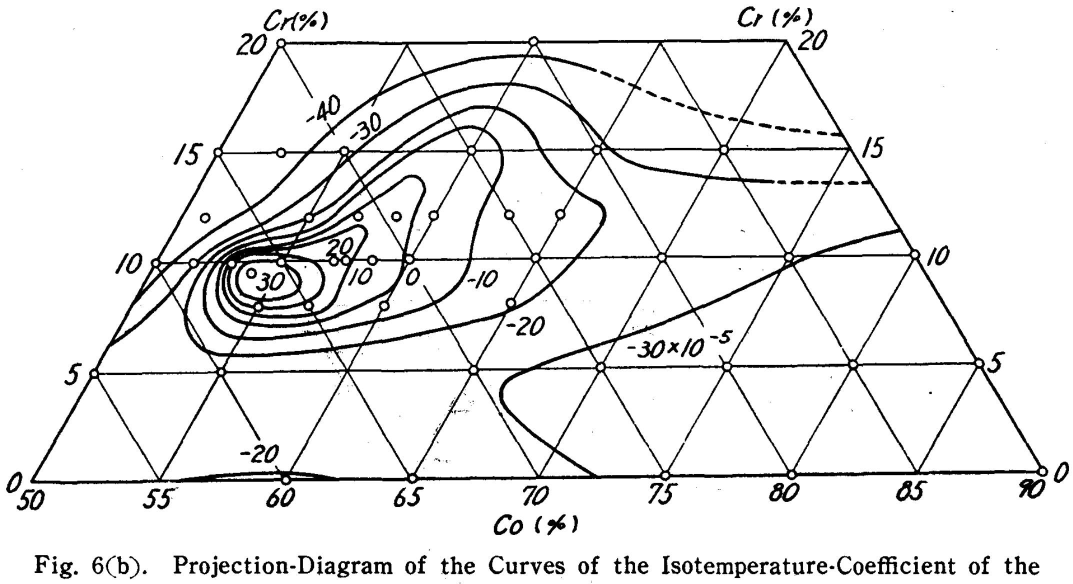


Fig. 6(b). Projection-Diagram of the Curves of the Isotemperature-Coefficient of the Rigidity Modulus of Co–Fe–Cr Alloys.

Thus, we see that there are two groups of alloys, one of which has a positive coefficient and the other a negative, a zero coefficient boundary existing between them. The alloys which have a comparatively small coefficient of rigidity modulus are collected in Table 2 together with the alloys having a small coefficient of Young's modulus(2). In the table, e shows the temperature coefficient of Young's modulus. These alloys are so-called co-elinvar which is very useful as the material for the hair spring of a chronometer, a watch and other measuring instruments or the helical spring of a seismograph and a spring balance.

Table 2. Some Examples of Co-elinvar.

Composition (%)			$e^{(2)}$ (0～50°)	g (20～50°)
Co	Fe	Cr		
57	35	8	$+1.7\times10^{-5}$	$+17.9\times10^{-5}$
60	32	8	-12.4	-2.5
51.5	38.5	10	-1.0	-31.5
57.5	32.5	10	$+1.2$	$+10.1$
60	30	10	-15.5	-0.2
58.5	29.5	12	$+4.4$	$+1.0$
60	28	12	-2.4	-4.3
60	25	15	-19.6	-0.9

Further, the present investigators are examining the influence of an addition of nickel to these properties of the alloys of cobalt, iron and chromium. The results of this investigation will be reported later.

Summary

The results of the present investigation may be summarized as follows:

(1) The rigidity modulus of the ternary alloys of cobalt, iron and chromium containing 50 to 90 percent of cobalt and less than 20 percent of chromium has been measured. The least value of the modulus obtained is 5.92×10^5 kg/cm^2 in the alloy of 65 percent of cobalt, 27 percent of iron and 8 percent of chromium. When the concentrations of the alloys go away from this composition, the modulus increases first rapidly and then gradually, and shows a greatest value of 9.34×10^5 kg/cm^2 in the alloy containing 50 percent of cobalt, 45 percent of iron and 5 percent of chromium. This result is similar to that for Young's modulus except that the position of the minimum value of rigidity modulus shifts towards the concentration of higher cobalt than in the case of Young's modulus.

(2) The temperature coefficients of rigidity modulus of the ternary alloys are generally negative and of common order, while, when the concentrations approach the composition of stainless-invar, the coefficient diminishes, first gradually and then rapidly, becomes zero and afterwards changes its sign. Finally, it reaches the positive maximum of $+35.9\times10^{-5}$ at the composition of 54 percent of cobalt, 36.5 percent of iron and 9.5 percent of chromium, which coincides with that of stainless invar. These results are similar to those for the temperature coefficient of Young's modulus, but, in the case of rigidity modulus, the range of the positive coefficients and the positive maximum are situated at the concentrations of higher

cobalt and lower chromium than in the case of Young's modulus. This fact may probably be caused by the difference of the texture of the specimens due to the degree of cold-drawing.

In conclusion, the present investigators wish to express their thanks to Mr. S. Tezuka, Mr. Y. Sugai and Mr. N. Seto for their kind assistance in taking the observations and making the preparation of the specimens. Part of the expense for the present investigation was payed with the grant in aid for fundamental scientific research from the Department of Education.